NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE EFFECT OF EXTENSION IN SYSTEM TECHNOLOGY ON CONTRACTOR COSTS AND PRODUCTION SCHEDULES DURING THE PROCUREMENT OF AIR-LAUNCHED TACTICAL MUNITIONS

by

Robert J. Ritchie

December 1990

Thesis Advisor: O. Douglas Moses

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE — *Form Approved OMB No 0704-0188*

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School; 6b OFFICE SYMBOL (If applicable): Code 37	7a NAME OF MONITORING ORGANIZATION: Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
THE EFFECT OF EXTENSION IN SYSTEM TECHNOLOGY ON CONTRACTOR COSTS AND PRODUCTION SCHEDULES DURING THE PROCUREMENT OF AIR-LAUNCHED TACTICAL MUNITIONS

12 PERSONAL AUTHOR(S)
Ritchie, Robert J.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ____ TO ____	1990, December	87

16 SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Technology Measurement; Technology and Cost; Cost Growth; Schedule Growth; Contractor Costs;

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This thesis investigates relationships between extensions in technology and both cost and schedule slippages in the development and production phases of weapons system acquisition. The primary objective is to determine if the amount of technology embodied in a given weapons system can be employed to predict a Department of Defense (DOD) contractor's performance in meeting cost and schedule targets. The analysis used a sample of 15 U.S. military tactical air-launched munitions systems. It begins with a review of the literature regarding technology measurement and its connection to cost and schedule outcomes. Next, measures of technological progress are developed and displayed. Third, the process of creating cost growth and schedule slippage measures are discussed. The relationships between technological complexity and cost and schedule outcomes are then empirically tested. Major findings indicate that measures of extension in

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL: Prof. O. Douglas Moses	22b TELEPHONE (Include Area Code): (408) 646-3218; 22c OFFICE SYMBOL: Code AS/Mo

DD Form 1473, JUN 86 — Previous editions are obsolete — SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 — UNCLASSIFIED

Approved for public release; distribution is unlimited

The Effect of Extension in System Technology on Contractor Costs and Production Schedules During the Procurement of Air-Launched Tactical Munitions

by

Robert J. Ritchie
Lieutenant Commander, Supply Corps, United States Navy
B.A., Bates College, 1978

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1990

Author: ______________________
Robert J. Ritchie

Approved by: ______________________
O. Douglas Moses, Thesis Advisor

____
Shu S. Liao, Second Reader

____
David R. Whipple, Chairman
Department of Administrative Sciences

ABSTRACT

This thesis investigates relationships between extensions in technology and both cost and schedule slippages in the development and production phases of weapons system acquisition. The primary objective is to determine if the amount of technology embodied in a given weapons system can be employed to predict a Department of Defense (DOD) contractor's performance in meeting cost and schedule targets. The analysis used a sample of 15 U.S. military tactical air-launched munitions systems. It begins with a review of the literature regarding technology measurement and its connection to cost and schedule outcomes. Next, measures of technological progress are developed and displayed. Third, the process of creating cost growth and schedule slippage measures are discussed. The relationships between technological complexity and cost and schedule outcomes are then empirically tested. Major findings indicate that measures of extension in technology are worthwhile for explaining production and total program cost growth.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION AND LITERATURE REVIEW

A. BACKGROUND

A number of prior studies have used data describing measures of performance and other properties and characteristics as indicators of technology embodied in a system. These studies then endeavored to relate these measures to contractor cost and schedule performance. This thesis is a follow-on to these works. This chapter begins with a literature review of the techniques currently available involving technology measurement and its relationship with cost and schedule outcomes. It will then describe how the concepts in those works can be used as the groundwork for the analysis conducted in this thesis and discuss the basic methodology to be used. This first chapter will conclude with a preview of subsequent chapters.

B. PURPOSE

The intent of this thesis is to determine what, if any, relationship exists between the state of the art in technology and advances in technology embodied in weapons systems and contractor cost and schedule performance during acquisition of these systems. It will attempt to analyze the particular relationships between technological sophistication and advances in technology of a set of U.S. military air-launched

tactical munitions systems and a Department of Defense (DOD) contractor's ability to achieve control over cost growth and schedule slippages in both the development and production phases.

C. LITERATURE REVIEW

In this section, several key studies are reviewed that apply to the objective of this thesis and to the methodology to be used in the analysis. That is, the following studies examine methods to create technology measures and/or procedures to relate the level of technology in a system to cost performance. Each of these studies has shown that variables reflecting system performance, properties, and characteristics can be combined to measure the amount of technology embodied in a system. These technology describing variables can also be used to measure advances in the technology of upgraded/updated systems. These studies require the accumulation of numerous technology describing variables that distinctly indicate a system's performance, properties, and characteristics. Each approach then combines variables into a single measure that reflects the quantity of technology in a given system. Some of the works have then attempted to relate the level of technology to system development and/or production costs. A common theme is an understanding that the cost of extending technology relates to the magnitude of the

extension.[1] [Refs. 1,2,3] The analysis in this thesis builds upon the work of the authors reviewed. The following reviews are presented in chronological order.

1. Alexander and Nelson, 1972

Alexander and Nelson [Ref. 6] use a linear regression method to analyze their data. A noteworthy point, applicable to the discussion in this thesis, lies in their discussion of the use of a graphically displayed, regression trend line to identify the average or expected date of technology of systems over time. This allowed them to display the level of technology embodied in a given system. Points representing individual systems that were plotted above the trend line indicated that the technology in that system was "ahead of its time." Similarly, points below the line indicated that the systems were "late" or "conservative" developments.

2. Dodson, 1977

In this study, Dodson [Ref. 7] used three technology indicators. He ran a multivariate regression with the year of development as the dependent variable. The regression equation was in the following form:

$$Y_e = k_0 + k_1X_1 + k_2X_2 + k_3X_3$$

---

[1]Important research by such authors as Dodson & Graver [Ref. 4] and Dodson [Ref. 5] are not reviewed here. These two studies, among others, made use of ellipsoidal hypersurfaces to represent levels of technology. They represent important contributions to the field of technology measurement, but are not directly relevant to the focus of this analysis.

where:

Y_e = The Year of Technology (defined as the year that the system should have been introduced given the technology embodied in the system)

k_i = The regression coefficients

X_i = The technology indicators.

He calculated Y_e for each system in the sample and postulated that if the actual year of development was less than Y_e, then the system was "ahead of its time." Similarly, if the actual year of development was greater than Y_e, then the system was technologically "behind the times" when it was introduced. Therefore, $Y_e - Y_{Actual}$ was a measure of the technological advance represented by each system in the sample.

In an effort to associate costs with technology, Dodson next conducted another regression with cost as the dependent variable and technology advance ($Y_e - Y_{Actual}$) as an independent variable. He estimated both Research & Development (R&D) costs and procurement costs in separate regressions. Procurement cost was approximated from a cost estimating relationship (CER) incorporating the Year of Technology. This was necessary to compensate for the changes in production technology over time. Dodson reasoned that an advanced design would be relatively more expensive to produce with older manufacturing technology. At the same time, advanced manufacturing technology should result in a drop in procurement cost. He found that his estimates for R&D costs

were not completely satisfactory, however. This was largely due, he explained, to certain unidentified costs of R&D that were not included in the regression model. Dodson had somewhat better success with procurement costs.

3. Gordon and Munson, 1981[2]

This paper examined technology extension and its measurement using two types of equations [Ref. 8]:

$$S = K_1V_1 + K_2V_2 + . . . + K_nV_n$$

and

$$S = V_1[K_2V_2 + K_3V_3 + . . . + K_nV_n]$$

where:

S = State of the Art (the current extent of technology)

K_i = A judgmental or statistical weight

V_i = The value of the ith technology describing variable.

The first is a simple linear equation combining weighted characteristics. The second equation is a multiplicative form that is intended to be used when one variable **must** be present.

An important new contribution made by Gordon and Munson in this paper was to propose factor analysis as a means to collect a large number of technology describing variables

---

[2]Discussion adapted from review in Greer [Ref. 1:pp. 11-13].

into groups that have similar relation to or influence on the state of the art in technology. The advantage of factor analysis is that it allows for a large number of variables to be incorporated into the model by aggregating several correlated variables into a few, more manageable, composite measures called factors. The factor scores can then be employed for further analysis. Factor analysis represents yet another tool for relating technology and cost measures.

4. <u>Knight, 1985</u>

Two important contributions were made in this study [Ref. 9]. First, Knight distinguished between functional and structural technology measures and related the two. He defined a functional measure of technology as: "The capability of each system to perform its intended tasks." [Ref. 9:p.107] Knight also studied functional technology measures over time. This study provided guidelines for data collection.

5. <u>Greer, 1988</u>

These previous studies examined techniques to define extensions in technology, usually with the use of regression analysis as a common thread. Technology describing variables were typically combined to produce single measures representing the amount of technology in a system. The "Year of Technology" was usually employed as the dependent variable in the regression equation. Several studies then attempted to relate the scale of technology to system costs.

Building on these works, Greer [Ref. 1] undertook to develop a cost estimating model, using technology measurement methods, that could both predict costs and be useful for cost control purposes. Using technology measures, he first developed a time regression to predict the amount of time required for development of a system. This predicted time was then used in a cost regression calculating an "ex ante" cost estimate for each system.

Next, the actual time for the project was compared to the predicted time to calculate a residual (similar to Dodson's $Y_e - Y_{Actual}$ computation). The cost regression was run again to produce a new cost estimate based on the residual project time. The difference between the ex ante cost estimate and the cost estimate based on actual time was called the "Variance Due to Time." This represents that portion of variance explained by time delays. Greer also compared actual cost to the cost estimate based on actual time to ascertain a "Cost Control Variance." This variance revealed the quality of a project's cost control.

In developing the two variance measures, Greer hoped to explain the causes of cost variance for each system he analyzed. The results indicated whether observed variances were due to time or to cost control. In order to control costs, he concluded, it was essential to explain the variance between predicted and actual costs.

Greer also noted that development cost is not a smooth function of time. "If a program drags on beyond its intended completion date, it becomes relatively more costly to compress the required accomplishment into an increasingly abbreviated time horizon." [Ref. 1:p. vi]

6. <u>Moses, 1989</u>

In this study, Moses [Ref. 3] revised and extended Greer's work. He employed the "Year of Technology" approach (the focus in this thesis) to technology measurement as did Alexander & Nelson and Dodson rather than Greer's use of the ellipsoid method.

Like Greer, Moses addressed the relationship between technology and development costs and created methods for determining development cost variances. In an important new thrust, the report extends the analysis to examine production costs as well as development costs. Moses used data for 18 satellite systems to empirically test this approach to technology measurement and cost prediction and control.

D. MEASURING EXTENSIONS OF TECHNOLOGY

The studies reviewed here focus on methods to measure technology. One commonly used method is the "Year of Technology" Regression approach. This procedure uses multiple regression to relate several technology describing variables and time in the following general form:

$$Y = K_0 + K_1X_1 + K_2X_2 + \ldots + K_nX_n + e$$

where:

Y = The actual year that the system was produced or became operational

K_i = Regression coefficients

X_i = Technology describing variables

e = Residual.

Values predicted from the regression equation for a given system represent the "Year of Technology" for that system. As Dodson noted, if the actual year that the system was produced or became operational is less than the calculated year of technology, then the system represents an advancement in technology.

According to Moses, the essence of the Year of Technology method is to combine a number of technology variables into summary measures and express them in terms of time (years). Using this approach, he created three technology measures for each system in his sample: STAND, ADVANCE, and REACH. These are briefly defined as follows:

- STAND--The actual year that the system becomes operational which represents, in general, where technology currently "stands." Stand equals "Y" in Dodson's equation $Y_e - Y$. For this thesis, STAND is equal to Full-Scale Development (FSD) Start Date.

  ADVANCE--The extension of technology beyond the current state of the art. This measure is the deviation from the trend line discussed by Alexander & Nelson. In Dodson's equation, ADVANCE = $Y_e - Y$.

- REACH--A measure of the level of technology embodied in a system equal to Dodson's "Y_e."

This thesis will use STAND, ADVANCE, and REACH measures to summarize the technology associated with a particular weapon system. These measures will then be used in an attempt to explain cost and schedule outcomes.

A related work by Lienhard [Ref. 10][3] supports the "Year of Technology" approach. In examining several technologies over time, Lienhard studied the rate that technology improves and whether this rate changes over time. He noted that, once established, the rate of improvement of a given technology does not change. If so, attempts to accelerate advances in technology "ahead of their time" could be extremely costly. Therefore, the Year of Technology approach appears sound and it is this approach that will be used in this analysis.

E. BENEFITS

Building on the techniques established in the literature, this analysis will examine a sample of several U.S. military tactical air-launched munitions systems. It will contribute to the existing body of knowledge by empirically analyzing these systems using the methods described earlier. It seeks to estimate and explain a government contractor's tendency towards cost growth and schedule growth resulting from

---

[3]Discussion adapted from Greer [Ref. 1:p. 38].

advances in and extensions to these high-technology weapons systems.

F. OBJECTIVES

The objective of this thesis is to determine if there is a relationship between the state of technology in air-launched tactical munitions and a contractor's performance in meeting cost and schedule targets. Using the techniques reviewed in the literature, the following will be undertaken:

- A statement and discussion of the hypothesis that a relationship may exist between system technology and contractor cost and schedule performance.
- Development of indicators of technology for air-launched tactical munitions that can be employed to assess a contractor's ability to meet cost and schedule targets.
- Using a "Year of Technology" analysis on tactical air-launched munitions data, construct summary technology measures.
- Examine, discuss, and display procedures for creating measures of cost and schedule growth.
- Perform a statistical analysis of the hypothesis and review results and findings.

G. SUBSEQUENT CHAPTERS

1. Chapter II

This chapter will begin with a description of the origin of the sample and the data sources for technology measures. Following techniques demonstrated by Moses [Ref. 3], technology measures for tactical air-launched munitions will be created using indicators of:

- Speed
- Range
- Guidance Systems
- Sensors
- System Reliability.

Next, data sources for cost and schedule outcomes will be discussed. The chapter will conclude by defining the hypothesis. The hypothesis is based on how three measures of technology: stand, advance, and reach, relate to cost growth and schedule slippages.

2. Chapter III

This chapter will examine the process of creating technology measures and will include the "Year of Technology" regression analysis and a display of measures. It will also examine the process of developing cost and schedule measures through a discussion and review of procedures and data in the study by Tyson et al. [Ref. 11].[4] It will address controls and contain a display of measures.

3. Chapter IV

Chapter IV will provide the statistical analysis of the hypothesis introduced in Chapter II. It will test the relationship of cost and schedule growth, during both development and production phases (as the dependent

---

[4]For brevity's sake, this 1989 study by Tyson, Nelson, Om, and Palmer is hereinafter referred to as the "Tyson study."

variables), and the level of system technology (reach, stand, and advance as the independent variables) in a regression analysis. Included will be a discussion and display of results.

4. Chapter V

This final chapter will summarize the key aspects of the analysis and present the conclusions of the study.

II. SAMPLE, DATA, AND HYPOTHESIS

This chapter is organized into four sections. The first presents the tactical air-launched munitions systems to be used as the sample in this thesis. The second and third sections discuss the data and its sources. Technology data are addressed first and are followed by cost and schedule information. With an understanding of the sample and data to be used in this analysis, the final section of this chapter will introduce the basic hypotheses.

A. SAMPLE

The sample consists of 15 tactical air-launched munitions systems used in the Tyson study [Ref. 11:see p. III-2]. Tyson's original sample consisted of 16 systems. One, the AGM-53A Condor, retired circa 1979, was omitted in this thesis due to a lack of available technology measures. Table II-1 is a list of the sample systems and their Full-Scale Development (FSD) start dates.

These 15 systems represent three distinct subsets of missile types with unique mission requirements: (1) Air-to-air (anti-air), (2) Air-to-surface (tactical air-launched), and (3) Air-to-Surface (helicopter launched). As will be seen in Chapter III, these mission differences will have an impact on the variable selection process. Tyson's data identifies

Table II-1

SAMPLE TACTICAL AIR-LAUNCHED MUNITIONS SYSTEMS

OBS	Name	Designation	FSDSD
1	Sparrow	AIM-7E	1960
2	Sparrow	AIM-7F	1966
3	Sparrow	AIM-7M	1978
4	Sidewinder	AIM-9L	1971
5	Sidewinder	AIM-9M	1976
6	Phoenix	AIM-54A	1962
7	Phoenix	AIM-54C	1977
8	HARM	AGM-88A	1978
9	Harpoon	AGM-84A	1973
10	Maverick	AGM-65A/B	1968
11	Maverick	AGM-65D/G	1976
12	AMRAAM	AIM-120A	1982
13	Hellfire	AGM-114A	1976
14	TOW	BGM-71A/B	1963
15	TOW2	BGM-71D	1978

the missile systems by mission, design, and series using standard missile system designation. A brief explanation of the missile designation structure is provided in Appendix A.

There are a variety of air-launched munitions that are not missiles--gravity bombs are one such example. However, this sample consists solely of missiles. Therefore, for the purposes of this thesis, the terms missile and munitions are used interchangeably.

The sample is spread over 22 years when grouped by FSD start date. All of the programs are still in production or in service with the U.S. Navy, Army, Air Force, and/or Marines or in foreign service. Where a successor system of a particular missile resulted in a design that was technologically indistinguishable from its predecessor, Tyson combined systems into a single program. Thus, for example, the AGM-65A and AGM-65B versions become the AGM-65A/B.

B. TECHNOLOGY DATA

Data, consisting of numerical values for the technology measures to be considered in the analysis, were obtained from a variety of sources [Refs. 12-17 and additional classified sources].[1] Prior to actual data collection, it was necessary to select the variables to be considered in this analysis.

The selection of measures describing the amount of technology embodied in each system required certain pre-considerations. According to Dodson and Graver, technology

[1]The author is indebted to the Naval Postgraduate School and, in particular, Dr. Ball of the Department of Aeronautical Engineering for help in developing technology measures. Invaluable assistance was also provided by MAJ Paul F. O'Sullivan, Jr., USA and MAJ Michael Staggs, USA.

describing properties must be, at least to some extent, a consequence of engineering development rather than a by-product of that process. The variables selected should be design goals of system development. Ideally, these variables should be arranged so that increasing values display greater technological sophistication. Additionally, the variables selected should be those whose values are determinable in the early stages of a system's life-cycle so that they may be used for predicting future cost and schedule performance [Ref. 4: pp. 13-14].

Technical expertise was sought to develop the list of technology measures. A listing of candidate variables describing the technical characteristics, properties, and performance criteria of the tactical air-launched munitions systems was developed. This candidate list is provided in Appendix B.

Some of these characteristics, properties, and performance measures were considered to be simply by-products of design or were not stated in a form that could reveal much about technological sophistication. These measures were dropped from further consideration. The list of candidates was further reduced by data availability. Due to the variety of missions represented in the sample, and due to programmatic and record-keeping differences among the military services, many of the candidate measures are not used or maintained for individual systems. The result of the data collection and

review process was the identification of 14 variables that could be used to describe the technology embodied in the missile systems. These variables are listed in Table II-2.

Values were obtained for each of the 14 variables, with one exception: MSR was not available for the AIM-120A AMRAAM, the newest system in the sample. The mean value of the Sparrow (AIM-7 series)--the system with the closest, similar mission (intermediate range air-to-air)--was inserted to preclude a distortion of the data to be used in later portions of the analysis.[2] With 14 variables to describe 15 systems, further variable reduction was necessary. This process will be discussed in Chapter III.

C. COST AND SCHEDULE DATA

This thesis employs cost and schedule data from the Tyson study [Ref. 11]. In this work, Tyson, et al., explored trends in cost and schedule outcomes of a variety of major acquisition programs. They also sought to determine the effectiveness of initiatives to improve these outcomes. The study examined cost growth and schedule slippages by equipment type (including tactical air-launched munitions), by time periods, by development and production phases, and by development type (new starts or major modifications). The

---

[2]Since portions of the variables or their values are classified, they will not be displayed here. As will be seen, only regression results are presented which are not compromisable.

TABLE II-2

VARIABLES DESCRIBING
TACTICAL AIR-LAUNCHED MUNITIONS TECHNOLOGY

Range (RNG) Variables:

- RNG1 - Maximum Missile Range (Meters)
- RNG2 - Minimum Missile Range (Meters)

Altitude (ALT) Variables:

- ALT1 - Maximum Missile Altitude (Meters)
- ALT2 - Minimum Missile Altitude (Meters)

Speed (SPD) Variables:

- SPD1 - Missile Speed (Mach)
- SPD2 - Maximum Platform Launch Speed (Mach)
- SPD3 - Minimum Platform Launch Speed (Mach)

Terminal Guidance System (TGS) Variables:

- TGS1 - TGS Redundancy
  Coded: 0 = Single System
  1 = Dual Systems
  2 = Multiple Systems
- TGS2 - TGS Reliability
  Coded: 0, 1, or 2 based on expert assessment of system reliability (classified).
- ECCM - Improved Electronic Counter Measures Defeating Capability
  Coded: 0 = No
  1 = Yes

Platform Sensor Variables:

- IMCC - Inertial Mid-Course Correction Capability
  Coded: 0 = No
  1 = Yes
- DSP - Digital Signal Processing Capability
  Coded: 0 = No
  1 = Yes

Missile Fuzing Variable:

- FUZE - Fuze Type
  Coded: 0 or 1 based, as above, on expert assessment of system reliability (classified).

Missile System Reliability (MSR) Variable:

- MSR - Percent Reliability, Given a Successful Launch

reason for interest in the Tyson study is its collection of cost and schedule histories for the sample of tactical air-launched munitions.

The Tyson study obtained cost and schedule information primarily from Selected Acquisition Report (SAR) data. Supplemental information was obtained from Development Concept (DCP) statistics and other data from the military services, Department of Defense (DOD) acquisition/program offices, and defense industry sources [Ref. 11, p. III-3].

Measures of outcome were based on:

- COST GROWTH--Development, Production, and Total: An indicator of good program performance is the ability of the contractor to develop and produce the system according to the cost target.

- SCHEDULE SLIPPAGE--Development and Production: As above, an indicator of good performance is the degree to which a system can be developed and produced within planned time frames.

The study produced measures for five program outcomes. These are listed in Table II-3.[3] They used the term "growth" in cost and schedule since most program changes reflected increases in program cost or time. The study found that, in a few cases, such as when development or production quantities were reduced, cost and schedule "growth" was negative. The

[3]They also examined quantity changes which "give clues to such issues as reasonableness of the development plan, the degree of production stability, and the prevalence of program stretchout." [Ref. 11:p. III-5] We restrict our discussion in this thesis to cost and schedule outcomes.

TABLE II-3

PROGRAM OUTCOMES

OUTCOME	CODE
Development Cost Growth	DCG
Production Cost Growth	PCG
Total Program Cost Growth	TPCG
Development Schedule Growth	DSG
Production Schedule Growth	PSG

process used for calculating program outcome measures will be discussed in Chapter III.

D. HYPOTHESES

This section discusses the proposed associations between a government contractor's performance in meeting cost targets and planned schedules and the technological complexity embodied in a weapons system. The purpose of the study is to determine if a relationship exists between technology extensions and cost growth and between technology extensions and schedule growth in both development and production phases of weapons system acquisition. The objective here is to hypothesize why such associations may exist.

The hypotheses, then, are based on how three measures of technology introduced in Chapter I, REACH, ADVANCE, and STAND, relate to cost growth and schedule slippages. There are five distinct areas to be examined: three involving cost growth and two involving schedule growth.

1. Technological Complexity and Cost Growth

The first three hypotheses rest on the idea that there is a direct relationship between cost growth of a given system and the technological complexity of the system. Two variables describe the technology associated with a given system: STAND and ADVANCE. STAND measures the current state of technology at the time of system development. This time is defined as the year of Full-Scale Development for each system. Thus, STAND measures the general state-of-the-art of missile technology at the point when each individual system is developed. It is hypothesized that costs become more difficult to control as the degree of technological complexity increases. Hence, cost growth is expected to be positively associated with STAND.

The second variable is ADVANCE, which measures the incremental change in technology achieved by the development program. Thus, ADVANCE measures the incremental jump in technology, beyond the prevailing state-of-the-art, associated with the specific system being created. It is hypothesized that costs become more difficult to control as the incremental

advance increases. Hence, cost growth is expected to be positively associated with ADVANCE.[4]

Three measures of cost growth are examined. To understand the differences between acquisition program phases, development and production cost growth, representing two distinct phases of DOD's weapons system acquisition strategy, are separated. Thus, development cost growth and production cost growth are two measures. The third is total program cost growth which is the total growth in costs for both the development and production phases. Although production costs are a much higher percentage of the total than development costs, development costs are still important because most technical difficulties are encountered in the development phase [Ref. 11:p. III-7]. The hypotheses involving cost growth are:

H_1: Development Cost Growth = f{STAND,ADVANCE}

H_2: Production Cost Growth = f{STAND,ADVANCE}

H_3: Total Program Cost Growth = f{STAND,ADVANCE}

2. Technological Complexity and Schedule Slippages

The fourth and fifth hypotheses concern time, measured as an increase (or decrease) of the schedule beyond the

[4]Recall that REACH was the third variable. Since REACH is the sum of STAND and ADVANCE there is no additional information and so, it is excluded from the analysis.

original estimate. Hypotheses concerning schedule slippage are analogous to those for cost growth. It is hypothesized that schedules become more difficult to meet as the degree of technological complexity increases. Hence, schedule growth is expected to be positively associated with STAND. It is also hypothesized that schedules become more difficult to control as the incremental technological advance represented by the particular system increases. Hence, schedule growth is expected to be positively associated with ADVANCE.

Two measures of schedule growth are examined. As with cost growth, development and production phases are separately viewed. Total schedule growth is not relevant since the various development and production contracts of a given program usually require dissimilar and unrelated scheduling commitments. The hypotheses for schedule growth are:

H_4: Development Schedule Growth = f{STAND,ADVANCE}

H_5: Production Schedule Growth = f{STAND,ADVANCE}

E. SUMMARY

This chapter has examined the sample to be analyzed and the sources of data. Using this information, the next step is to develop technology, cost, and schedule measures to be used to test the hypotheses presented in this chapter. Chapter III will discuss the process of creating summary technology

measures and will provide a review of Tyson's procedures for creating cost and schedule measures. Chapter IV will then test the hypotheses.

III. TECHNOLOGY, COST, AND SCHEDULE MEASUREMENT

In order to test the hypotheses presented in the previous chapter, summary measures of technology, cost, and schedule are required. The process of creating these measures is the next step. Technology measures will be addressed first, followed by cost and schedule measures.

A. CREATING TECHNOLOGY MEASURES

In Chapter II, data sources were introduced and the initial selection of technology describing variables was discussed. In this section, the process of creating measures of technology is continued. The first step in this process is variable reduction. The second step is the creation of summary measures of technology.

1. Variable Reduction

Recall from Chapter II that data were obtained on 14 variables for the 15 systems in the sample. Since this many variables, given a sample size of only 15, is statistically unmanageable, further variable reduction was necessary. Three methods of variable reduction were chosen. The first two used statistical methods. The third method involved a judgmental process based on technical expertise.

The first method of variable reduction used a univariate regression. This method rests on the assumption

that technology should increase with time and that good technology variables should show a positive relationship to time. Thus, a time regression is used to identify the best individual variables. The year of development, which was previously defined as the FSD start date, was the dependent variable in a series of regression equations. Each of the 14 technology variables was used in a separate regression as a single independent variable.

Some results of this initial series of regressions were unexpected. That is, coefficients of several of the variables were negative, when they were expected to be positive. This could signify that these variables were not the indicators of technology that the technical experts thought them to be. Since, upon consultation, they thought this unlikely, a review of the data values was undertaken. Three categories of the variables describing missile performance--RNG, ALT, and MSR--were found to be affected by mission requirements. Recall from the description of the sample that there are, at least, three distinct groups of tactical air-launched munitions in the 15 system sample: (1) air-to-air, (2) air-to-surface (tactical air-launched), and (3) air-to-surface (helo launched). It was determined that design considerations of a given system dictated certain performance parameters. This made direct comparisons among the three different groups difficult, if not impossible. Restricting the sample to just AIM or AGM series missiles was

not considered an acceptable alternative since that would lead to still more problems due to an increasingly small sample size ($n < 15$).

To make the RNG, ALT, and MSR variables comparable amongst all three groups, data transformation was necessary to normalize the measures by group. Actual data values were converted to ratios. To accomplish this, some additional data collection was necessary. Actual values were obtained for the earliest, operational version of each missile system, if not already in the sample. Thus, for the AIM-7 Sparrow and the AIM-9 Sidewinder, the "A" or "B" series values, representing the earliest date of technology, were included to compute the ratios. A value of "1" was assigned to the lowest value, representing the most primitive level of technology, in each of the three mission groups. With the original data value of this system in the denominator and each of the remaining system values, in turn, as the numerator, the ratios were then computed for each of the systems in the sample. In short, values for RNG, ALT, and MSR were normalized by dividing a group-specific baseline value for RNG, ALT, and MSR respectively. Once the variables were re-configured into ratios, the individual univariate regressions were run again; this time with much better results.

The next step was to establish criteria for selection of the most significant variables. Upon review of the output,

the criteria chosen was an R^2 greater than or equal to .10 and a P-Value less than or equal to .15. Five of the 14 variables met these criteria. They are listed in Table III-1. This array of variables was labelled Version A.

TABLE III-1

VARIABLE REDUCTION: UNIVARIATE REGRESSION RESULTS, VERSION A

Variable	R^2 (%)	p-Value
ALT2	16.3	.136
TGS2	18.7	.107
ECCM	34.8	.021
IMCC	18.3	.111
FUZE	19.4	.100

The second method of variable reduction used was stepwise regression. Again the dependent variable was FSD date. Also, again, the objective was to identify a small set of variables most highly associated with time. Use of the normalized data obtained via the ratio transformation was continued in this process. The advantage of stepwise regression is that it provides an ability to isolate a subset of predictor (independent) variables that yield an optimal

equation. The stepwise method selects from a large set of candidates those independent variables that best predict the dependent variable [Refs. 22, 23]. Both forward inclusion and backward elimination routines were used. The best results were obtained with forward inclusion. Three variables were selected in this manner--ALT2, SPD3, and ECCM--with a relatively high R^2 of 64.96%. Results of this stepwise regression are contained in Table III-2 and is labelled Version B.

TABLE III-2

VARIABLE REDUCTION: STEPWISE REGRESSION, VERSION B

Stepwise regression of FSDSD on 14 predictors, with n = 15

Step	1	2	3
Constant	69.50	71.74	69.07
ECCM	8.30	10.00	5.00
T-Ratio	2.44	3.39	1.39
SPD3		11.20	20.00
T-Ratio		2.04	3.07
ALT2			3.20
T-Ratio			2.05
s	5.75	5.16	4.58
R^2	34.85	51.58	64.96

Since neither the univariate nor the stepwise methods were completely satisfactory for use in the Year-of-Technology analysis to follow, it was decided that the variables selected by both methods should be used and to add a third list of variables. This third list was derived using a judgmental approach based on the opinion of technical experts as to those variables that should best describe the level of technology in these systems. Several combinations of variables developed by the experts were tested by both univariate and stepwise regression to ensure that they were statistically sound. Combinations that contained the "RNG" and "MSR" variables achieved unexpected results in the form of negative coefficients, indicating a non-positive relationship to the passage of time, so were dropped from further consideration. A final version, acceptable to the experts and statistically sound, was eventually settled on. The variables selected in this manner are listed in Table III-3. This third version was labelled Version C.

2. <u>Year of Technology</u>

With three reduced sets of technology variables now selected, the next step was to create summary measures that describe the extension in technology of each missile system. The process used was the Year of Technology approach. Recall that the Year of Technology approach relates technology measures to time to predict the expected year that the system should be produced. The difference between the actual year,

TABLE III-3

VARIABLE REDUCTION:
JUDGMENTAL METHOD,
VERSION C

ALT2	ECCM
SPD3	IMCC
TGS2	FUZE

which in our case is the FSD start date, and the expected or computed year is used as the measure of the advance in technology for the individual system.

Following this process, the years of FSD start of each missile program were separately regressed against the variables selected in Versions A, B, and C. Results are contained in Appendix C. Models B and C explain a moderately high portion of the variance (adjusted R^2 = 55.4% and 51.9%, respectively). Version A explains significantly less (adjusted R^2 = 24.2%) due in part to the number of predictor variables in the model. Each coefficient is positive which is consistent with the values of the technology describing variables reflecting increasing technology through time. This furnishes some confirmation that the variables selected in the previous step appropriately reflect the extent of technology and technology growth.

Tables III-4, III-5, and III-6 are plots of the Year of Full-Scale Development (Y) versus Year of Technology (Y_e). Values for STAND, ADVANCE, and REACH reflecting technological complexity or extension were then computed for each system in each of the three versions. Results are contained in Table III-7.[1]

B. COST AND SCHEDULE MEASURES

This section is primarily a synopsis of Tyson's creation of measures for program cost and schedule growth outcomes [Ref. 11]. As discussed earlier, Tyson separated cost and schedule growth into development and production phases. Separate, though similar, procedures were used for cost and schedule measurement.

1. Cost Growth Measures

The study created cost growth ratios using the following procedures and controls:

- Program cost estimates were collected for each system. A base-year, constant dollar figure was used so that inflation would not distort comparisons among programs that were established at different times.

---

[1]There are other methods for determining measures of STAND, ADVANCE, and REACH. An alternative that Dr. Moses tested involved designating an "individual system as a reference point. Candidates might be a) an immediate predecessor system or b) the predecessor system with the greatest REACH (maximum predecessor technology). The technology embodied in either reference system would constitute STAND, and ADVANCE would be measured as deviations from the specific reference system...These alternatives were explored with no material enhancement of the analysis." [Ref. 2:p. 17fn]

TABLE III-4

YEAR OF TECHNOLOGY PLOT
VERSION A

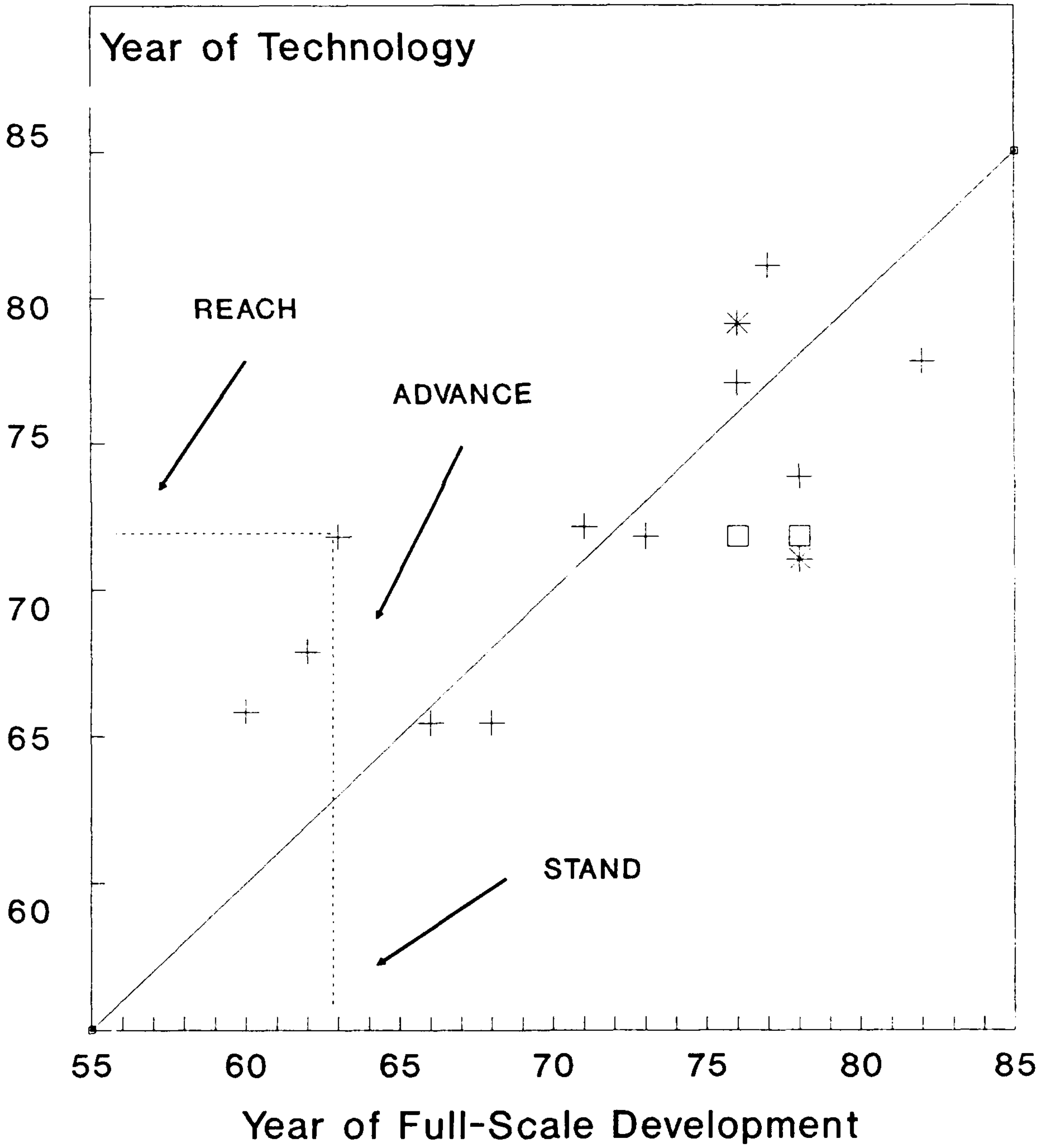


TABLE III-5
YEAR OF TECHNOLOGY PLOT
VERSION B

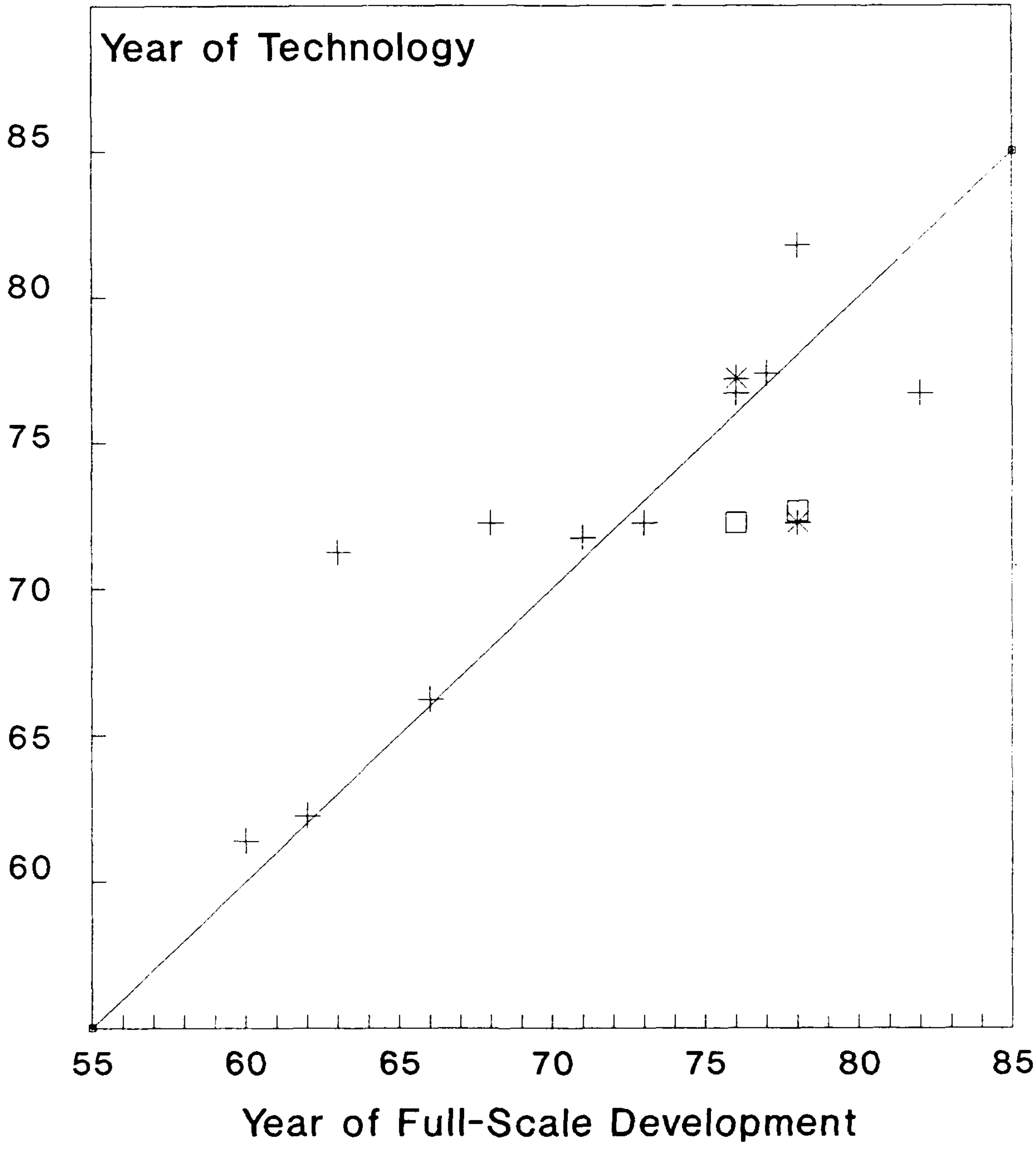


TABLE III-6

YEAR OF TECHNOLOGY PLOT VERSION C

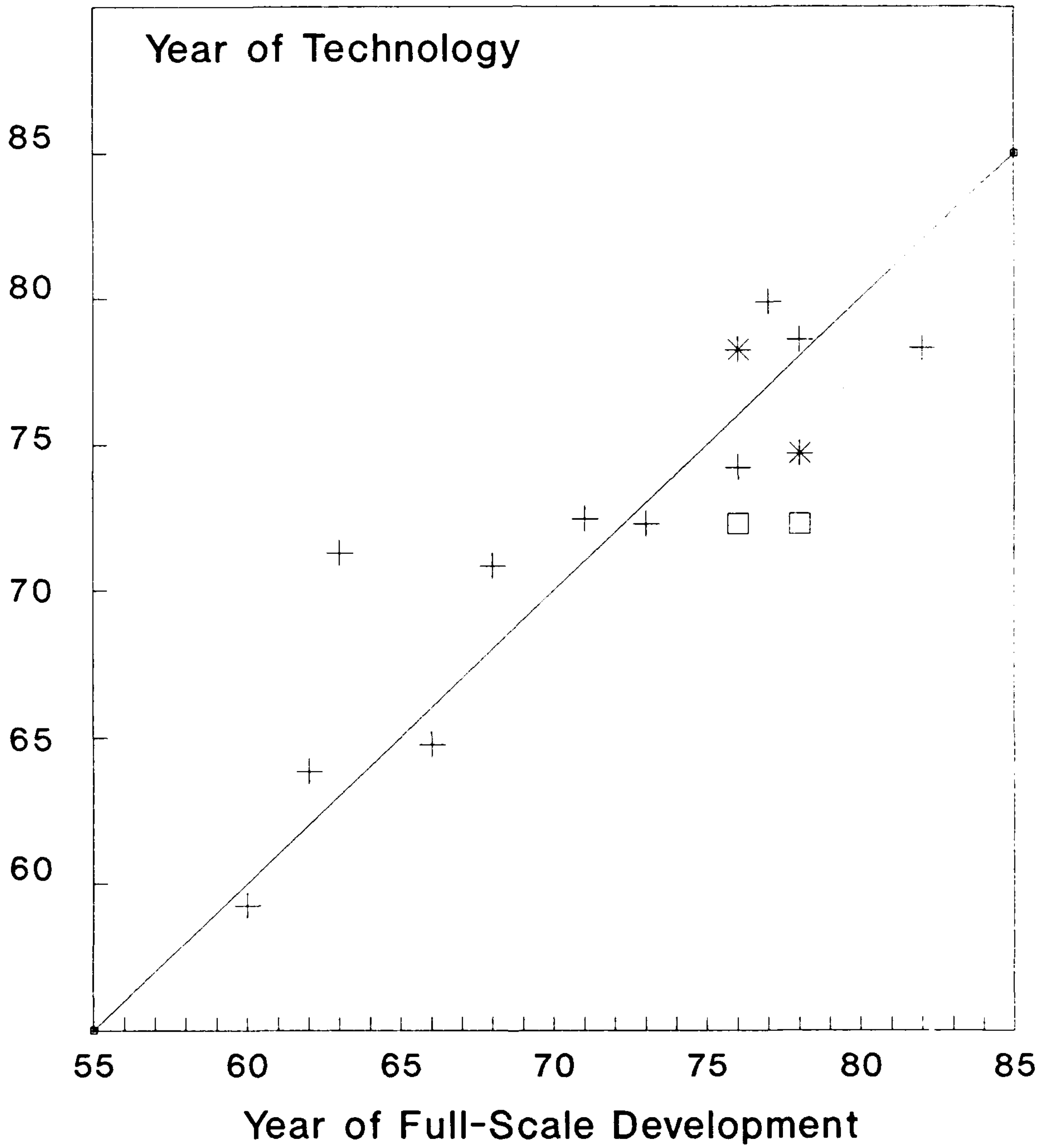


TABLE III-7

TECHNOLOGY MEASURES

SYSTEM	STAND	A-ADV	A-REACH	B-ADV	B-REACH	C-ADV	C-REACH
AIM-7E	60	5.83	65.83	1.39	61.39	-0.74	59.26
AIM-7F	66	-0.55	65.45	0.23	66.23	-1.26	64.74
AIM-7M	78	-4.14	73.86	3.70	81.70	0.57	78.57
AIM-9L	71	1.15	72.15	0.74	71.74	1.46	72.46
AIM-9M	76	1.04	77.04	0.70	76.70	-1.78	74.22
AIM-54A	62	5.86	67.84	0.23	62.23	1.83	63.83
AIM-54C	77	4.09	81.09	0.30	77.03	2.86	79.86
AGM-88A	78	-6.98	71.02	-5.76	72.24	-3.29	74.71
AGM-84A	73	-1.19	71.81	-0.76	72.24	-0.71	72.29
AGM-65A /B	68	-2.55	65.45	4.24	72.24	2.83	70.83
AGM-65D /G	76	3.09	79.09	1.20	77.20	1.21	77.21
AIM-120A	82	-4.09	77.91	-5.30	76.70	-2.86	79.14
AGM-114A	76	-4.19	71.81	-3.76	72.24	-3.71	72.29
BGM-71A /B	63	8.81	71.81	9.24	72.24	9.29	72.29
BGM-71D	78	-6.19	71.81	-5.76	72.24	-5.71	72.29

- Development costs were obtained for the period from program start to initial operating capability (IOC) date. Those development costs after IOC were excluded because these costs generally consisted of modifications or other changes not within the scope of the original development project.

Development Cost Growth (DCG) ratios were then calculated by dividing the actual development cost at IOC by the development cost estimate at FSD start using the following formula:

$$DCG = \frac{\textit{Development Cost at IOC}}{\textit{Development Cost Estimate at FSD}}$$

For production cost growth, there were additional considerations. The first was that the data for production cost represented the cost to the government, not simply the overall cost of the project. Therefore, production cost growth ratios more accurately refer to price growth. Second, the study took account of changes in quantities procured as programs progressed. Adjustments to costs included charges for schedule, engineering, inflation, and estimating changes. Using a "price-improvement methodology" that included these controls, Tyson created price-improvement learning curves to calculate the cost of the originally planned quantity. The production cost growth (PCG) ratio was based on a comparison of the original estimate and the later, revised cost at the original planned quantity. The production cost growth formula can be stated as:

$$PCG = \frac{\textit{Production Cost at Production Start}}{\textit{Adjusted Estimate of Production Cost (Original Qty)}}$$

The final cost outcome measure, Total Program Cost Growth (TPCG), was then determined. This ratio was the sum of the estimate of development costs at IOC and production cost at production start divided by the sum of the development cost estimate at FSD plus the adjusted estimate of production costs based on the original quantity. The formula was:

$$TPCG = \frac{Dev.\ Cost\ at\ IOC + Pr.\ Cost\ at\ Start}{Dev.\ Cost\ at\ FSD + Adjusted\ Pr.\ Cost}$$

2. <u>Schedule Measures</u>

Providing measures of schedule slippage was less exacting. The formula that Tyson used for development schedule growth is simply a measure of time. The ratio was computed by dividing the actual span in months from development start (FSD) to IOC by the original estimate prior to FSD. The formula used to compute the development schedule growth (DSG) ratio was:

$$DSG = \frac{Actual\ FSD \rightarrow IOC\ (Months)}{Estimated\ FSD \rightarrow IOC\ (Months)}$$

Production schedule growth was measured using the same technique. The production span was defined as the period from contract award to the end of production or, if still in production, the last year of planned funding. The production schedule growth (PSG) ratio formula is:

$$PSG = \frac{Actual\ Production\ Start \rightarrow End\ (Months)}{Estimated\ Production\ Start \rightarrow End\ (Months)}$$

Actual values of the ratios from the Tyson study for these five program outcomes are contained in Table III-8.

TABLE III-8

OUTCOME MEASURES

SYSTEM	DCG	DSG	TPCG	PCG	PSG
AIM-7E	0.84	1.00	1.07	1.08	3.11
AIM-7F	4.25	3.90	1.74	1.58	1.93
AIM-7M	0.98	1.46	1.29	1.31	1.61
AIM-9L	4.89	2.45	2.25	2.07	2.76
AIM-9M	2.04	1.01	1.10	1.01	2.44
AIM-54A	1.54	1.07	1.39	1.35	1.20
AIM-54C	1.67	1.45	1.93	2.01	3.71
AGM-88A	2.03	1.05	1.47	1.39	1.61
AGM-84A	1.17	1.36	1.53	1.64	3.05
AGM-65A/B	1.15	1.46	0.95	0.84	2.17*
AGM-65D/G	1.07	1.98	1.53	1.58	2.14
AIM-120A	1.44	1.80	1.06	1.05	1.11
AGM-114A	1.09	1.44	1.39	1.61	2.38
BGM-71A/B	1.20	1.45	1.70	1.78	2.27
BGM-71D	1.70	1.02	0.98	0.95	0.94

* PSG for the AGM-65A/B Maverick was not provided in the Tyson study's acquisition program database. The mean value of PSG was inserted to preclude a distortion of the data for use later in the analysis.

Source: [Ref. 11:App. A]

C. SUMMARY

This chapter has reviewed Tyson's process of creating measures of cost growth and schedule slippage. Using techniques from prior studies, measures of technological complexity and extension have also been created. With these key building blocks in place, the next step is to begin the process of examining relationships between technology and cost and schedule growth.

IV. STATISTICAL ANALYSIS AND TESTS

The purpose of this chapter is to describe the analysis of the hypotheses regarding cost and schedule growth and their relationship to technological complexity and extension. In the previous chapter, techniques developed in previous studies were used to create measures of technology. Procedures and data used in the Tyson study to create measures of cost and schedule growth were also examined. Having developed these measures, the main purpose of this thesis is to test for the existence of relationships between cost and schedule growth and the level of technology embodied in systems. This is to be accomplished by statistically testing, using regression analysis, the five hypotheses presented in Chapter II.

This chapter is organized into four sections. The first section will discuss methods to examine, evaluate, and prepare the variables to be used in the regression analysis. The second section will discuss the procedures used in the regression analysis itself and will review results. Based on these results, the third section will explore some approaches to improve upon those results, including the introduction of control factors. The final section will summarize the results.

A. ANALYSIS OF VARIABLES

Prior to testing the hypotheses, the variables required examination to determine their suitability for use in the regression analysis. The first step was to check for normality and multicollinearity, identify possible outliers in the data, and highlight any variables that might need transformation [Refs. 23,24]. Several outliers were discovered.

1. Outliers.

The following alternatives for processing outliers were considered.

a. Disregard Outliers

Simply put, this means to include the outliers in the regression analysis. Since outliers can have a significant impact on correlation and regression tests, this was rejected.

b. Discard Outliers

This procedure eliminates the detrimental impact on the tests. This too was rejected, however, since to delete these observations would result in substantially reducing the sample size. This was unacceptable considering the already small number of systems in the sample.

c. Data Transformation

There are several methods for transforming data values for improved fit. These include square-root, inverse function, power, log, exponential, and ratio transformation.

However, since the data consisted of a mixture of variables (values were, in some cases, negative, some positive, some fractional greater than one, and some fractional less than one), no one method was mathematically feasible. Therefore, this method was also rejected.

d. Truncate Outliers

Truncating outliers involves establishing maximum and minimum data values, or boundaries, for each of the variables. Outliers are first identified by observation of the distribution. Maximum and minimum values are set using somewhat subjective methods to define a "reasonable range" for the distribution. Values falling above or below this range are then truncated to the minimum/maximum boundaries of the range. In other words, outliers values are pulled in to form a more compact distribution. Since outliers were identified for a number of variables, this method was chosen.

2. Processing Outliers

The "reasonable range" for outliers was identified by reviewing box and stem-and-leaf plots of the variables. Data values more than one and one-half times the normal distribution box-plot length (+ or -) from the extreme values of the middle 50% of the data (essentially the data values residing at or nearest to the first and third quartiles) were selected for truncation. This represented values well outside the normal distribution range (approximately 150% greater than

or less than the nearest non-outlier value).[1] The following approach was used to assign new values to truncated data values.

a. High Outliers

DCG for the AIM-7F (refer to Table III-8), by way of example, was identified as one of a number of high outliers. The highest and second highest non-outliers were then identified. The outlier value was truncated at twice the percentage difference between the two highest non-outliers. The following formula was used to assign truncated values [Ref. 24:p. 61]:

$$O_R \quad = \quad [((D_H - D_{H-1}/D_{H-1}) \times 2) + 1] \times D_H$$

where:

O_R = The outlier replacement value

D_H = The highest non-outlier value

D_{H-1} = The second highest non-outlier value

The computed value for O_R then replaces the original value for use in the subsequent regression analysis.[2] Since this procedure resulted in some truncated values still falling outside our "reasonable range," two additional controls were employed. A subjective limit of 20% was set to limit the

---

[1]This method represents the default procedure of outlier selection in MINITAB [Ref. 22:p. 210].

[2]Using the DCG example, D_H = 2.04 and D_{H-1} = 2.03, then: O_R [((= [((2.04 - 2.03/2.03) x 2) +1] x 2.04 = 2.06. The truncated data value is then established as 2.06.

extremes of truncated values. Also, if more than a 10% difference existed between the two highest non-outliers, then the outlier value was replaced with the lower of O_R or the value 20% larger than the highest non-outlier.

b. Low Outliers

Although there were no low outliers were identified, they would be processed using a similar technique. The following formula was used [Ref. 24:p. 62]:

$$O_R = [1-((D_{L-1} - D_L/D_{L-1}) \times 2)] + 1$$

where:

O_R = Same as defined above

D_L = The lowest non-outlier

D_{L-1} = The second lowest non-outlier.

As above, the value of O_R replaced the original outlier values. Similar controls were also used.

c. Summary

The outliers that were "pulled in" using these procedures were the B-ADVANCE and C-ADVANCE values of the BGM-71A/B TOW missile, DCG and DSG of the AIM-7F Sparrow missile, and DCG of the AIM-9L Sidewinder missile. With the data values for both dependent and independent variables now "cleaned," the actual analysis was begun.

B. TESTS OF HYPOTHESES

The next step was to test the hypotheses. This was done using multiple regression with Tyson's measures of cost and schedule growth as single dependent variables. The measures of technological complexity and extension (STAND and ADVANCE), in three separate versions, were the independent variables. The dependent and independent variables are summarized in Table IV-1. As explained in Chapter II, REACH was not used in this initial series of regressions. Results of the regressions are contained in Tables IV-2 through IV-6.

TABLE IV-1

TECHNOLOGY AND OUTCOME MEASURES

TECHNOLOGY (Independent Variables)	OUTCOMES (Dependent Variables)
STAND (Current State)	Development Cost Growth
ADVANCE (Extension)	Production Cost Growth
REACH (Amount)	Total Program Cost Growth
	Development Schedule Growth
	Production Schedule Growth

TABLE IV-2

DEVELOPMENT COST GROWTH, MULTIVARIATE REGRESSIONS

Dependent Variable	Independent Variable	COEFF	t	p-Value	Model Statistics
DCG	Constant	0.9830	0.54	0.597	F = .26
	STAND	0.0067	0.27	0.792	R^2 = 4.2%
	A-ADV	-0.0105	-0.29	0.775	Adj. R^2 = 0.0%
					P = .774
DCG	Constant	1.5610	1.04	0.317	F = .88
	STAND	-0.0014	-0.07	0.947	R^2 = 12.8%
	B-ADV	-0.0461	-1.13	0.279	Adj. R^2 = 0.0%
					P = .439
DCG	Constant	0.9990	0.69	0.506	F = .38
	STAND	0.0064	0.31	0.759	R^2 = 6.0%
	C-ADV	-0.0285	-0.56	0.586	Adj. R^2 = 0.0%
					P = .692

TABLE IV-3

PRODUCTION COST GROWTH,
MULTIVARIATE REGRESSIONS

Dependent Variable	Independent Variable	COEFF	t	p-Value	Model Statistics
PCG	Constant	-0.137	-0.09	0.926	F = 1.62
	STAND	0.021	1.08	0.300	R^2 = 21.3%
	A-ADV	0.051	1.79	0.099	Adj.R^2 = 8.2%
					P = .238
PCG	Constant	1.229	0.89	0.392	F = .17
	STAND	0.003	0.14	0.892	R^2 = 2.8%
	B-ADV	0.021	0.55	0.593	Adj.R^2 = 0.0%
					P = .843
PCG	Constant	0.714	0.60	0.558	F = 1.44
	STAND	0.010	0.61	0.550	R^2 = 19.4%
	C-ADV	0.070	1.68	0.118	Adj.R^2 = 6.0%
					P = .274

TABLE IV-4
TOTAL PROGRAM COST GROWTH,
MULTIVARIATE REGRESSIONS

Dependent Variable	Independent Variable	COEFF	t	p-Value	Model Statistics
TPCG	Constant	0.405	0.28	0.786	F = 1.11
	STAND	0.014	0.70	0.496	R^2 = 15.6%
	A-ADV	0.041	1.43	0.178	Adj.R^2 = 1.5%
					P = .362
TPCG	Constant	1.4530	1.08	0.303	F = .22
	STAND	-0.0003	-0.02	0.987	R^2 = 3.5%
	B-ADV	0.0196	0.54	0.602	Adj.R^2 = 0.0%
					P = .807
TPCG	Constant	0.940	0.82	0.431	F = 1.51
	STAND	0.007	0.44	0.666	R^2 = 20.1%
	C-ADV	0.0679	1.69	0.118	Adj.R^2 = 6.8%
					P = .260

TABLE IV-5

DEVELOPMENT SCHEDULE COST GROWTH, MULTIVARIATE REGRESSIONS

Dependent Variable	Independent Variable	COEFF	t	p-Value	Model Statistics
DSG	Constant	1.123	0.55	0.595	F = 0.02
	STAND	0.005	0.18	0.858	R^2 = 0.40%
	A-ADV	0.008	0.04	0.840	Adj.R^2 = 0.00%
					P = .978
DSG	Constant	0.697	0.40	0.697	F = 0.27
	STAND	0.111	0.46	0.651	R^2 = 4.4%
	B-ADV	0.035	0.74	0.474	Adj.R^2 = 0.0%
					P = .764
DSG	Constant	0.6450	0.40	0.696	F = 0.52
	STAND	0.0121	0.54	0.598	R^2 = 8.00%
	C-ADV	0.0573	1.02	0.328	Adj.R^2 = 0.00%
					P = .606

TABLE IV-6

PRODUCTION SCHEDULE COST GROWTH, MULTIVARIATE REGRESSIONS

Dependent Variable	Independent Variable	COEFF	t	p-Value	Model Statistics
PSG	Constant	0.337	0.10	0.921	F = 1.85
	STAND	0.034	0.75	0.470	R^2 = 25.1%
	A-ADV	0.113	1.74	0.109	Adj.R^2 = 11.5%
					P = .203
PSG	Constant	2.049	0.74	0.475	F = 1.13
	STAND	0.002	0.06	0.953	R^2 = 17.1%
	B-ADV	0.103	1.29	0.223	Adj.R^2 = 2.0%
					P = .357
PSG	Constant	2.19700	0.88	0.396	F = 1.25
	STAND	0.00003	0.00	0.999	R^2 = 17.2%
	C-ADV	0.12067	1.38	0.191	Adj.R^2 = 3.5%
					P = .321

1. Development Cost Growth and Technological Complexity

Recall that the first hypothesis is that there is a direct relationship between cost growth in the development phase (DCG) and the scope of the development task measured in terms of technological complexity. The regression results are mediocre. Coefficients for STAND and/or ADVANCE are negative in all three versions which is unexpected. The low values for R^2 and the poor significance levels render this model essentially without much meaning.

2. Production Cost Growth and Technological Complexity

The second hypothesis is that production cost growth (PCG) is directly related to technological complexity. The results of these multivariate regressions are somewhat better than for DCG. The coefficients are positive as expected and the R^2 values for Versions A and C are much higher. As a whole, however, the models are not significant at traditional levels.

3. Total Program Cost Growth and Technological Complexity

With disappointing results for DCG and PCG, it was not surprising that the results obtained for total program cost growth (TPCG) were also unimpressive. Except for Version B, coefficients were positive as expected. R^2 values were lower than for PCG, but closer to PCG than to DCG. This may reflect the greater influence of production costs than development costs on total program costs, as put forward by Tyson.

Somewhat surprisingly, the R^2 and adjusted R^2 values for Version C increased.

4. Development Schedule Growth and Technological Complexity

The fourth hypothesis suggested a direct relationship between development schedule growth (DSG) and the STAND and ADVANCE measures of technology. Coefficients were positive in all three versions, but again, the models were insignificant.

5. Production Schedule Growth and Technological Complexity

The fifth and final hypothesis is that a direct relationship exists between production schedule growth (PSG) and technology STAND and ADVANCE. Perhaps the best overall results were obtained from these regressions. Coefficients were positive in all three versions. The R^2s were relatively high compared to the previous models. The highest adjusted R^2 of all of the models was obtained from Version A. Yet again, however, the models are not significant at traditional levels.

C. OTHER CONSIDERATIONS

1. Additional Tests

The relatively poor results obtained from the regressions suggested a return to the data transformation process discussed earlier in this chapter (see Section A.1.c). This was done in an effort to improve the outcomes of the regressions. Each of the data transformation techniques was tried, in turn and in combination--where mathematically

feasible--on both the dependent and independent variables. Multiple regressions were then rerun on the transformed variables. Despite the multitude of regression run in this manner, in no case was there a material enhancement of the models.

Univariate regressions were also explored. STAND, ADVANCE, and REACH were separately used as single independent variables. Regressions were run on the original data as well as transformed data in all combinations. Again, no material improvement was noted.

2. Control Factors That Affect Cost Growth

Since the results to this point were not particularly satisfying, a new direction was explored. The Tyson study identified several factors that affect cost growth. The most significant were program stretch and several acquisition/contracting initiatives such as multi-year procurement, competition, prototyping, design-to-cost, total package procurement, fixed price development, and contract incentives. Tyson's factors are summarized in Appendix D.

In discussing program stretch, the Tyson study reasoned that DOD and Congress "have sometimes met budgetary constraints by stretching out the production schedule, buying the same quantity over a longer schedule, or buying a lessor quantity over the same period." [Ref. 11:p. V-1] They hypothesized that program stretch, measured as schedule growth divided by quantity growth, contributes to cost growth. They

performed a series of univariate regressions with cost growth --development, production, or total program--as the dependent variable and stretch as the independent variable. Their findings indicated that program stretch was a strong, positive determinant of both production and total program cost growth, but not development cost growth.

Tyson then examined whether acquisition/contracting initiatives were associated with lower cost growth. They again used univariate regression analysis with cost growth as the dependent variable and the acquisition/contract initiative as the independent variable. Their findings indicated the following relationships:

- Fixed price development contracts (FPD) were positively related and contract incentives for FSD (I-FSD) were negatively related to development cost growth (DCG).
- Total package procurement (TPP) was positively related and contract incentives in the production phase (I-PRD) were negatively related to production cost growth (PCG).
- Total package procurement (TPP) was positively related while both FSD (I-FSD) and production (I-PRD) contract incentives were negatively related to total program cost growth (TPCG).

Tyson's finding suggested new tests. When program stretch and acquisition/contracting factors are controlled for the technology measures, STAND and ADVANCE could prove useful as predictors of cost growth. The following new models, using Tyson's variables as controls, were developed[3]:

---

[3]Actual data values for the control factors are contained in Appendix E.

H_6: **DCG = f{STAND,ADVANCE,I-FSD,FPD}**

H_7: **PCG = f{STAND,ADVANCE,I-PRD,TPP,STRETCH}**

H_8: **TPCG = f{STAND,ADVANCE,I-FSD,I-PRD,TPP,STRETCH}**

where:

I-FSD, FPD, I-PRD, TPP and STRETCH are as defined above.

Multivariate regressions were performed to test the new models. Results are contained in Tables IV-7, IV-8, and IV-9. The DCG models were, once again, unimpressive. The best results were obtained for production cost growth and total program cost growth using Version C measures of STAND and ADVANCE. While the overall models are not significant, the t-statistics and p-values for ADVANCE are meaningful. This tends to indicate that, when STRETCH and acquisition/ contracting factors are controlled, ADVANCE is useful as a predictor of production and total program cost growth.

D. RESULTS

Low significance levels and the small explanation of variability (R^2) for the initial models was a common result. The low explanatory ability of all the DCG models was not entirely unexpected. Both Dodson [Ref. 7] and Moses [Ref. 3] used technology variables in an attempt to predict development cost (using direct dollar measures of development cost) with little success. While they attributed their poor results to incomplete modelling, the similarly poor results here with

TABLE IV-7

DEVELOPMENT COST GROWTH WITH CONTROLS, MULTIVARIATE REGRESSIONS

Dependent Variable	Independent Variable	COEFF	t	p-Value	Model Statistics
DCG	Constant	0.671	0.32	0.753	F = 0.19
	STAND	0.013	0.03	0.675	R^2 = 6.9%
	A-ADV	-0.013	0.04	0.752	Adj.R^2 = 0.0%
	I-FSD	-0.146	-0.44	0.668	P = .941
	FPD	-0.324	-0.50	0.630	
DCG	Constant	1.184	0.75	0.473	F = 0.72
	STAND	0.007	0.31	0.764	R^2 = 22.3%
	B-ADV	-0.067	-1.45	0.177	Adj.R^2 = 0.0%
	I-FSD	-0.287	-0.90	0.387	P = .598
	FPD	-0.673	-1.04	0.321	
DCG	Constant	0.645	0.39	0.706	F = 0.29
	STAND	0.013	0.56	0.589	R^2 = 10.3%
	C-ADV	-0.040	-0.70	0.499	Adj.R^2 = 0.0%
	I-FSD	-0.197	0.59	0.568	P = .879
	FPD	-0.418	-0.64	0.538	

TABLE IV-8

PRODUCTION COST GROWTH WITH CONTROLS, MULTIVARIATE REGRESSIONS

Dependent Variable	Independent Variable	COEFF	t	p-Value	Model Statistics
PCG	Constant	-0.546	-0.27	0.793	F = 1.15
	STAND	0.023	0.92	0.382	R^2 = 39.0%
	A-ADV	0.039	1.26	0.239	Adj. R^2 = 5.2%
	I-PRD	0.310	1.16	0.276	P = .401
	TPP	-0.172	0.49	0.732	
	STRETCH	0.030	0.23	0.826	
PCG	Constant	0.469	0.27	0.796	F = 0.97
	STAND	0.011	0.49	0.635	R^2 = 35.1%
	B-ADV	0.037	0.97	0.356	Adj. R^2 = 0.0%
	I-PRD	0.251	0.90	0.392	P = .482
	TPP	-0.560	-1.11	0.297	
	STRETCH	0.023	0.17	0.870	
PCG	Constant	0.263	0.18	0.858	F = 2.24
	STAND	0.015	0.86	0.414	R^2 = 55.4%
	C-ADV	0.091	2.34	0.044	Adj. R^2 = 30.6%
	I-PRD	0.124	0.52	0.617	P = .139
	TPP	-0.783	-1.83	0.100	
	STRETCH	0.039	0.35	0.735	

TABLE IV-9

TOTAL PROGRAM COST GROWTH WITH CONTROLS, MULTIVARIATE REGRESSIONS

Dependent Variable	Independent Variable	COEFF	t	p-Value	Model Statistics
TPCG	Constant	0.180	0.09	0.933	F = 0.90
	STAND	0.013	0.51	0.623	R^2 = 40.4%
	A-ADV	0.044	1.26	0.244	Adj.R^2 = 0.0%
	I-FSD	0.266	0.87	0.411	P = .537
	I-PRD	0.183	0.54	0.606	
	TPP	0.015	0.03	0.977	
	STRETCH	-0.020	-0.15	0.886	
TPCG	Constant	1.161	0.61	0.558	F = 0.73
	STAND	0.001	0.05	0.959	R^2 = 35.3%
	B-ADV	0.037	0.91	0.389	Adj.R^2 = 0.0%
	I-FSD	0.161	0.54	0.603	P = .642
	I-PRD	0.194	0.54	0.603	
	TPP	-0.402	-0.77	0.464	
	STRETCH	-0.023	-0.16	0.874	
TPCG	Constant	1.253	0.86	0.412	F = 2.05
	STAND	0.002	0.09	0.934	R^2 = 60.6%
	C-ADV	0.105	2.55	0.034	Adj.R^2 = 31.1%
	I-FSD	0.350	1.42	0.193	P = .170
	I-PRD	-0.088	-0.29	0.780	
	TPP	-0.679	-1.62	0.145	
	STRETCH	-0.012	-0.11	0.915	

development cost growth offer some confirmation that technology is not a direct predictor of cost outcomes in the development phase.

The results obtained while using control variables in addition to the technology variables to predict cost growth were improved, indicating that ADVANCE is potentially a useful measure for estimating production and total program cost growth.

Chapter V will summarize the thesis and present conclusions based on the results obtained in this chapter.

V. SUMMARY AND CONCLUSIONS

A. SUMMARY

This thesis has explored hypothesized relationships between technological complexity and both cost growth and schedule growth in the development and production phases of weapons system acquisition. A key objective was to develop measures of technology, cost growth, and schedule growth that would be useful for conducting a statistical analysis of possible relationships.

The first step was to identify technology describing properties, characteristics, and performance measures for the sample of tactical air-launched munitions. With the assistance of technical experts, data was obtained for 14 variables measuring range, speed, altitude, electronics, and reliability. To make the number of variables more manageable for the subsequent analysis, the set of variables was reduced by three separate methods: univariate regression, stepwise regression, and a judgmental selection method, labelled Versions A, B, and C. All subsequent analysis was conducted three times, once based on each of the three reduced sets of variables.

Using the Year of Technology Approach established in previous studies, the reduced set of technology describing variables was employed to determine the level of technology

embodied in each missile system. The set of technology measures were regressed against the actual year in which the systems were developed. The resulting regression model produced three measures of technology for each missile system:

- STAND--The actual year in which the missile system was developed which measures the current state of technology.
- ADVANCE--The extension of technology beyond the current state of the art for a given system.
- REACH--The total level of technology embodied in each system.

Measures of program outcomes developed by Tyson, Nelson, Om, and Palmer [Ref. 11] were used as cost growth and schedule growth measures. In their study, Tyson et al. created ratio measures of cost growth by dividing the actual development or production costs by the costs estimated at the beginning of the project. Similarly, schedule growth ratios were calculated by dividing the actual length of the development or production project by the time estimated at the beginning of the project. In both cases, certain controls were introduced to ensure accuracy in the ensuing ratios.

The next step was to statistically test for the existence of relationships between cost and schedule growth and technological complexity. Each of the measures of cost growth and schedule growth were regressed on STAND and ADVANCE. The results of these initial regressions were unimpressive.

In an effort to improve upon these models, data transformation techniques were employed. Various combinations of

square-root, inverse function, power, log, exponential, and ratio transformation of the data were tested without material enhancement of the results. Various other univariate regression tests were experimented with, but again with no improvement of the results noted.

As a final test, a number of control factors that affect cost and schedule growth were introduced. These factors included program stretchout, a measure of how government attempts to meet budgetary constraints by buying the same quantity over a longer period of time or a smaller quantity within the original schedule. Other control factors consisted largely of acquisition initiatives, including total package procurement, fixed price development, and contract incentives in the development and production phases. Program stretchout and the acquisition initiatives with the strongest affect on cost growth were used as additional independent variables in a series of multivariate regressions. The results, while still not highly significant, nevertheless indicated that ADVANCE is useful as a predictor of production and total program cost growth.

B. CONCLUSIONS

The overall low significance levels and extremely small explanation of variability in the models establishes that measures of technological complexity and extension are not strong predictors of cost or schedule growth in either the

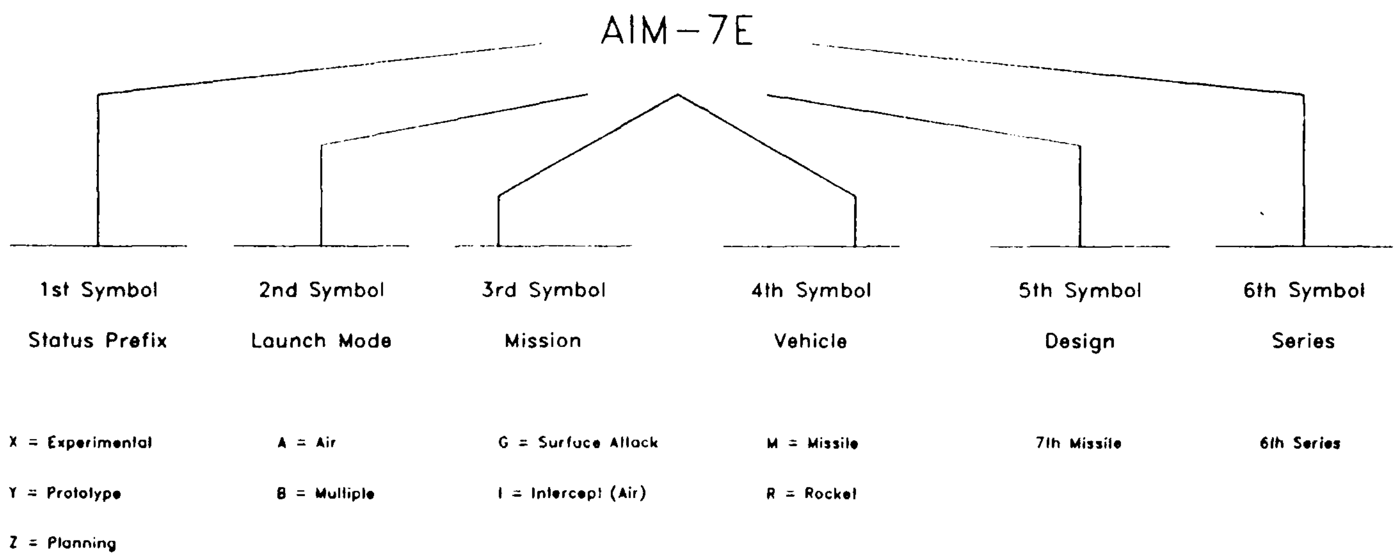
development or production phases of tactical air-launched munitions acquisition. The results obtained from both development cost and development schedule tests offers some confirmation that technological complexity is not a direct predictor of program outcomes in the development stage. The use of control factors as additional predictors of program outcomes provided some improvement in the results. This indicates that technology measures alone are not strong or dominant explainers of cost or schedule growth, but when obscuring factors are controlled for, technological extension (as measured by ADVANCE) is apparently related to production and total program cost growth.

The results have some limitations. The 15 tactical air-launched munitions systems were a small sample. In this small sample, three distinct missile groups were merged together. Data collection for technology variables was, to some extent, confined to those measures common to each of the three groups. This suggests that improved technology describing measures could be obtained for a more homogenous sample of missiles. It is possible, as well, that cost and schedule growth measures are not fully comparable between the three missile groups. This indicates that improved results may be achieved through the use of a larger and more homogenous sample of systems.

APPENDIX A

MISSILE DESIGNATION SYSTEM

A chart describing the Department of Defense (DOD) system for identifying missile programs is provided below.



[Source: Refs 13, 21]

MISSILE DESIGNATION SYSTEM

APPENDIX B

PROPERTIES, CHARACTERISTICS, AND PERFORMANCE MEASURES DESCRIBING TACTICAL AIR-LAUNCHED MUNITIONS TECHNOLOGY

- Acquisition (Seeker Range)
- Airframe Structure
- Attack Azimuth Angle
- Aerodynamic Performance
- Boost
- Chaff Defeating Capability
- Digital Signal Processing Capability
- Electronic Counter-Measures Defeating Capability
- Flare Defeating Capability
- Format Target Capability
- Fuzing Success
- Fuzing System Performance
- Guidance Success
- Imaging (Target/Background Reflections)
- Inertial Mid-Course Correction
- Inertial Reference
- Kill Probability (Pk)
- Launch Acceptability Regions (LARS)
- Launch Platform Speed
- Launch Success
- Lethality
- Look-Down, Shoot-Down Capability
- Mid-Course Guidance Performance
- Missile Message Accuracy
- Missile Altitude Capability
- Missile Range Capability
- Missile Speed Capability
- Multiple Target Capability

- No-Escapes Zones
- Propulsion Management
- Propulsion System Performance
- Sensor Performance
- Safe Separation
- Seeker Mode
- Stability and Control
- Software Assessment
- Software Validation and Verification
- Terminal Guidance System Redundancy
- Terminal Guidance System Reliability
- Warhead Performance
- Weapon Effectiveness
- Weapon Reliability
- Weather

Primary Source: [Refs. 19,20]

APPENDIX C

YEAR OF TECHNOLOGY REGRESSION ANALYSIS

Version A

The regression equation is:

FSDSD = 65.1 + 0.38 ALT2 + 3.18 TGS2 + 4.90 ECCM + 0.87 IMCC + 2.38 FUZE

Predictor	Coef	Stdev	t-ratio	p-val
Constant	65.077	4.064	16.01	0.000
ALT2	0.377	1.733	0.22	0.833
TGS2	3.180	1.963	1.62	0.140
ECCM	4.896	5.276	0.93	0.378
IMCC	0.866	5.885	0.15	0.886
FUZE	2.381	4.393	0.54	0.601

s = 5.972   R-sq = 51.3%   R-sq(adj) = 24.2%

Analysis of Variance

SOURCE	DF	SS	MS	F	p-val
Regression	5	337.90	67.58	1.89	0.191
Error	9	321.03	35.67		
Total	14	658.93			

SOURCE	DF	SEQ SS
ALT2	1	107.36
TGS2	1	153.69
ECCM	1	65.91
IMCC	1	0.46
FUZE	1	10.48

Version B

The regression equation is:
FSDSD = 69.1 + 3.17 ALT2 + 4.96 ECCM + 20.0 SPD3

Predictor	Coef	Stdev	t-ratio	p-val
Constant	69.066	2.180	31.68	0.000
ALT2	3.169	1.546	2.05	0.065
ECCM	4.964	3.580	1.39	0.193
SPD3	20.017	6.510	3.07	0.011

s = 4.581   R-sq = 65.0%   R-sq(adj) = 55.4%

Analysis of Variance

SOURCE	DF	SS	MS	F	p-val
Regression	3	428.07	142.69	6.80	0.007
Error	11	230.87	20.99		
Total	14	658.93			

SOURCE	DF	SEQ SS
ALT2	1	107.36
ECCM	1	122.29
SPD3	1	198.42

Unusual Observations

Obs.	ALT2	FSDSD	Fit	Stdev.Fit	Residual	St.Resid
14	1.00	63.00	72.24	1.76	-9.24	-2.18*

* Denotes an observation with a large standardized residual.

Version C

The regression equation is:

FSDSD = 68.2 + 20.3 SPD3 + 2.63 ALT2 + 1.77 ECCM
+ 4.91 IMCC + 0.73 TGS2 + 3.15 FUZE

Predictor	Coef	Stdev	t-ratio	p-val
Constant	68.203	3.472	19.65	0.000
SPD3	20.301	8.159	2.49	0.038
ALT2	2.632	1.651	1.59	0.150
ECCM	1.767	4.386	0.40	0.698
IMCC	4.913	4.961	0.99	0.351
TGS2	0.728	1.848	0.39	0.704
fuze	3.149	3.512	0.90	0.396

s = 4.756   R-sq = 72.5%   R-sq(adj) = 51.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p-val
Regression	6	477.95	79.66	3.52	0.052
Error	8	180.98	22.62		
Total	14	658.93			

SOURCE	DF	SEQ SS
SPD3	1	34.02
ALT2	1	353.70
ECCM	1	40.34
IMCC	1	28.99
TGS2	1	2.72
fuze	1	18.18

Unusual Observations

Obs.	SPD3	FSDSD	Fit	Stdev.Fit	Residual	St.Resid
14	0.000	63.00	72.29	2.23	-9.29	-2.21*

* Denotes an observation with a large standardized residual.

APPENDIX D

CONTROL FACTORS THAT AFFECT COST GROWTH

NEW/MOD	New vs. modification programs.
TIME	Time period: programs distinguished by year of FSD start--late 1960s, the early 1970s, the late 1970s, the 1980s.
PROD-U	Programs that started production in 1985 or before. Only programs with production starts before 1985 were considered.
PRO	Prototype programs vs. programs that did not use a prototype.
STRETCH	A measure of program stretchout equal to production schedule growth divided by production quantity growth.
C-PRD	Programs that included competition in their acquisition/contracting strategy.
DTC	Design-to-Cost contracts.
MYP	Multi-Year Procurement contracts.
FPD	Fixed Price Development contracts. Coded: 0 without FDP, 1 with FPD.
TPP	Total Package Procurement contracts. Coded: 0 without TPP, 1 with TPP.
I-FSD	Contracting incentives in the Full-Scale Development phase. Coded: 0 without incentives, 1 with incentives.
I-PRD	Contracting incentives in the production phase. Coded: 0 without incentives, 1 with incentives.

Source: [Ref. 11:App. A]

APPENDIX E

COST GROWTH OUTCOME CONTROL MEASURES[1]

SYSTEM	I-FSD	FPD	I-PRD	TPP	STRETCH
AIM-7E	1	0	1	0	9.1471
AIM-7F	1	0	1	0	1.1627
AIM-7M	1	0	1	0	1.1667
AIM-9L	1	0	1	0	2.2439
AIM-9M	0	0	0	0	1.0749
AIM-54A	0	1	0	0	1.2245
AIM-54C	1	0	1	0	0.7794
AGM-88A	1	0	1	0	1.5333
AGM-84A	1	0	1	0	3.2105
AGM-65A/B	0	0	0	1	2.1356*
AGM-65D/G	1	0	1	0	1.0974
AIM-120A	0	1	0	0	1.1100
AGM-114A	1	0	0	0	1.2020
BGM-71A/B	0	0	1	0	3.8475
BGM-71D	1	0	1	0	1.0562

*STRETCH FOR the AGM-65A/B Maverick was not provided in the Tyson study's acquisition program database. The mean value of STRETCH was inserted to preclude a distortion of the data for use later in the analysis.

Source: [Ref. 11:App. A]

---

[1]Refer to Appendix D for an explanation of control measures.

LIST OF REFERENCES

1. Greer, Willis R. Jr., "A Method for Estimating and Controlling the Cost of Extending Technology," Monterey, CA: Naval Postgraduate School Technical Report NPS-54-88-002, 1988.

2. Moses, O. Douglas, "Estimating and Explaining the Production Cost of High-Technology Systems: The Case of Military Aircraft," Monterey, CA: Naval Postgraduate School Technical Report NPS-54-89-07, 1989.

3. Moses, O. Douglas, "Estimating and Controlling the Cost of Extending Technology: A Revision and Extension, Monterey, CA: Naval Postgraduate School Technical Report #NPS-89-06, 1989.

4. Dodson, E.N. and C.A. Graver, "An Approach to Quantitative Measurement Advances in State of the Art," Santa Barbara, CA: Internal Memorandum (Releasable) IMR-997, General Research Corporation, 1969.

5. Dodson. E.N., "A General Approach to Measurement of the State of the Art and Technology Advance," Technology Forecasting, 1970, pp. 391-408.

6. Alexander, A.J. and J.R. Nelson, "Measuring Technological Change: Aircraft Turbine Engines," Santa Monica, CA:The Rand Corporation Report #R-1-17-ARPA/PR, 1972.

7. Dodson, E.N., "Technological Change and Cost Analysis of High-Technology Systems," IEEE Transactions on Engineering Management, May 1977, pp. 38-45.

8. Gordon, T.J. and T.R. Munson, "A Proposed Convention for Measuring the State of the Art of Products or Processes," Technological Forecasting and Social Change, 20, 1981, pp. 1-26.

9. Knight, K.E., "A Functional and Structural Measurement of Technology," Technological Forecasting and Social Change, 27, 1985, pp. 107-127.

10. Lienhard, J.H., "The Rate of Technological Improvement Before and After the 1830's," Technology and Culture, July 1979, pp. 515-530.

11. Tyson, K., J. Nelson, N. Om, and P. Palmer, "Acquiring Major Systems: Cost and Schedule Trends and Acquisition Initiative Effectiveness," Alexandria, VA: Institute of Defense Analysis IDA Paper P-2201, March 1989.

12. Friedman, Norman. US Naval Weapons, London: Conway Maritime Press, 1983.

13. Lennox, Duncan and Arthur Rees, eds., Jane's Air-Launched Weapons, Coulsdon, Surrey, UK: Jane's Defense Data, 1989.

14. Nicholas, Ted and Rita Rossi, U.S. Missile Data Book, 1990, 14th Ed. Fountain Valley, CA: Data Search Associates, 1989.

15. Polmer, Norman, Ships and Aircraft of the U.S. Fleet, 14th Ed. Annapolis: Naval Institute Press, 1987.

16. Zeitak, G. and J. Arlan, eds., Missiles and Missile Systems: An International Directory, Rehovot, Israel: A to Z, Ltd., 1987.

17. General Dynamics Corporation, Inc., Pomona Division, The World's Missile Systems, 8th Ed., August 1988, Pomona, CA: General Dynamics, 1988.

18. Department of Defense Instruction (DODINST) 4120.15 series, Model Designation of Military Aircraft, Rockets, and Missiles.

19. Eichblatt, Emil J., Jr., Test and Evaluation of an Air-to-Air Radio Frequency Guided Missile, Pt. Mugu, CA: Pacific Missile Test Center, 1986.

20. Eichblatt, E.J., Jr. and A. Pignaturo, "Missile Performance," in Test and Evaluation of the Tactical Missile, Emil J. Eichblatt, ed., Washington, DC: American Institute of Aeronautics and Astronautics, Inc., 1989, pp. 13-72.

21. SAS User's Guide: Statistics, Version 5 Edition, SAS Institute, Inc., 1985.

22. Schaefer, Robert L. and Richard B. Anderson, The Student Edition of MINITAB, Statistical Software, Reading, MA: Addison-Wesley Publishing, CO., Inc., 1989.

23. Liao, Shu S., Regression Techniques for Managerial Planning & Control, Unpublished Text [Photocopy] used by Permission of the Author.

24. Hicky, John S., Financial Condition of Government Contractors and Control of Production Costs in the Procurment of Major DOD Aircraft Weapons Systems, Master's Thesis, Naval Postgraduate School, Monterey, CA: December 1989.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 52 Naval Postgraduate School Monterey, California 93943-5002	2
3.	Professor O.D. Moses, Code AS/Mo Naval Postgraduate School Monterey, California 93943-5000	1
4.	Professor S.S. Liao, Code AS/Lc Naval Postgraduate School Monterey, California 93943-5000	1
5.	LCDR R.J. Ritchie, SC USN 37 Hickory Road Braintree, Massachusetts 02184	2